F-9110

DEVICE FOR PRODUCING A FINISHED CONTOUR OF A WORKPIECE BY GRINDING AND A METHOD FOR THIS PURPOSE

The invention relates to a device according to the introductory portion of claim 1 as well as to a method according to the introductory portion of claim 8.

For processing workpieces by grinding, the unfinished parts must have a contour, which is oversized within tolerance limits in comparison to the dimensions of the finished components. Since the unfinished parts fulfill the tolerance limits differently, the grinding program usually is designed so that the material is approached by sensing it. This leads to unnecessary air overruns (air grinding), during which no material is removed. These air overruns require unnecessary manufacturing time.

Especially for manufacturing built camshafts, the cam lobes and other functional components of camshafts are produced as unfinished parts according to tolerance specifications and mounted on the camshaft. In this connection, there are tolerance limits, within which the external contour of the unground, mounted cam lobe/functional component lies. This contour is referred to as the contour of the unfinished part and must have a grinding allowance.

After the installation, the cam lobes, bearing positions and any other functional surfaces are ground. At the same time, the grinding allowance is removed. The allowance is required in order to obtain a truly ground surface at the end of the processing and to be sure that the actual contour is not less than the nominal contour (finished contour).

According to the state of the art, the grinding takes place in several steps in such a way, that the grinding wheel, program-controlled, is moved very quickly as close as possible to the external perimeter of the contour of the unfinished part, the permissible tolerances being taken into consideration. Subsequently, the actual grinding process is commenced. During the actual grinding process, the grinding wheel is moved program-controlled at a specified rate of advance and a specified rotational speed to the nominal dimensions of the finished contour, which is to be ground. This delivery motion takes place relatively slowly, so that the workpiece, which is to be ground, does not overheat and the grinding wheel is not damaged. Depending on the thickness of the layer, which is to be ground, the delivery rate is faster at the beginning (rough machining) than later on (finishing, fine finishing). There is no further delivery when the nominal contour is reached. The workpiece is "sparked free". After a certain period of "sparking free", the workpiece has the nominal dimensions, that is, the finished contour and the process is terminated by moving the grinding wheel back rapidly. In this connection, the delivery motions, which repeatedly take place consecutively, are referred to as several steps of the process.

The programs, required for triggering the grinding wheels, contain values for the axial and radial advances (rotational speeds of the workpiece) as well as the radial deliveries, with which the grinding wheels are moved towards the workpiece. There are grinding machines with one spindle and grinding machines with several spindles.

It is a disadvantage of the previously known control programs for grinding machines that, depending on the size of the contour of the unfinished part, that is, depending on the actual grinding allowance of the unground functional component, the grinding wheel is moved along very slowly to the contour of the unfinished functional component, in some cases, over several 1/10 mm, in spite of the absence of contact with the workpiece. In expert circles, this procedure frequently is also referred to as air grinding. Moreover, the duration of the air grinding varies depending on the position of

the contour of the unfinished part in the tolerance field. As a result, an unnecessarily large amount of time is required for the grinding in many cases. In addition, the demand for reliable manufacturing processes to meet high quality standards results in the permissible tolerance range not being exhausted fully, resulting, in the majority of cases, in unnecessarily long air grinding. However, air grinding cannot be omitted since unfinished workpieces time and again have or may have the largest permissible contour.

It is an object of the invention to indicate a device and a method, with which the time, required for producing a finished contour of a workpiece, having a contour of an unfinished part, by grinding in several steps, is shortened as much as possible and, nevertheless, breakage of the tool or an impermissible heating of the component is prevented.

With regard to the device, this objective is accomplished pursuant to the invention by a device with the distinguishing features of claim 1. Advantageous developments are described in claims 2 to 7. With regard to the method, the objective is accomplished by a method with the distinguishing features of claim 8. Advantageous developments of the method are given in claims 9 and 10.

Advantageously, unnecessary air grinding, which prolong the processing time, is avoided by the solution described above. Due to the fact that the measuring is separated functionally from the grinding machine, a further reduction in the working time of the grinding machine, which is expensive in relation to the testing device, is furthermore achieved.

In one concrete embodiment, the invention relates to a device for grinding a finished contour of cam lobes of a camshaft with a grinding machine and a control device controlling the latter, the control device being able to specify grinding programs, which contain specified values with regard to the grinding parameters, such as the RPM

of the grinding means and/or of the workpiece, rate of advance, delivery and axial positions of the workpiece.

Pursuant to the invention, the device preferably has the following components:

- a measuring device for measuring the unfinished contour of the workpiece, which is to be ground,
- a plant control computer for determining and/or selecting one or more grinding programs,
- a first data-transfer device between the measuring device and the plant control computer as well as a second data transfer device between a plant control computer and the control device, it being possible to supply the values of the contour of the unfinished part, measured by the measuring device, over the first data transfer device to the plant control computer and, depending on these values, to determine and/or select at least one grinding program in the plant control computer and supply it over the second data transfer device to the control device and to control the grinding machine from the control device in accordance with the grinding program determined and/or selected.

Moreover, to begin with, it is immaterial whether the data connection is established by means of a fixed connection, such as a cable or radio, etc., or by means of connection, which is not fixed, such as a diskette or markings on the workpiece, that is, the respective camshaft, etc.

In a preferred embodiment, both data connections are constructed as fixed connections in the form of cables. The data is transferred over the usual protocols or bus systems used in industrial control technology, such as Profibus or Interbus. The plant

control computer may be an industrially usable personal computer, a microprocessor or a different data-processing device.

Furthermore, the invention relates to a method for producing a finished contour of a workpiece, having an unfinished contour, by grinding in several steps, preferably at the cam lobes of a camshaft, the contour of the unfinished part of the workpiece being ground away by a specifiable amount in each step, so that the contour of the workpiece is in the finished state of the last step.

Pursuant to the invention, the following steps are carried out for this method:

a) the contour of the unfinished part of the workpiece is measured before the grinding process is commenced;
b) the values determined are transmitted directly or indirectly to a control device;
c) depending on these values measured, either a grinding program is calculated, which is adapted to the actual contour of the unfinished part and for which the supplying of grinding agent to the grinding machine is controlled taking into consideration the actual contour of the unfinished part, or a specified and stored grinding program is selected, for which, in comparison to the remaining grinding programs that may be selected, the control of the delivery of the grinding agent of the grinding machine (3) is adapted best to the actual contour of the unfinished part.

In this connection, the grinding programs are determined in the following manner. The extent to which the grinding wheel can be moved at the maximum delivery rate in the direction of the workpiece that is to be ground is determined from the measurement of the contour of the unfinished part. In the ideal case, the grinding wheel is moved at the maximum delivery rate into the immediate vicinity of the contour of the

unfinished part. However, for safety reasons the grinding wheel cannot be moved completely against the measured contour of the unfinished part. Instead, air grinding over a distance of 0.02 mm to 0.1 mm must be set. The magnitude of the distance depends on the accuracy of the system measuring the contours. At the same time, the grinding allowance, that is, the thickness of the material that is to be ground away, is determined from the contour of the unfinished part. From that, the various ranges for the rough machining, finishing and finishing grinding and, with that, the associated delivery speeds are fixed. In this connection, the material, including the hardness and the geometric configuration of the workpiece, which is to be ground, are important. Thin components cannot dissipate as much heat as thick solid components. Different amounts of heat are released at the same delivery speed, depending on the nature of the material. In the same way, the RPM of the workpiece and of the tool are fixed, each depending on the capability of the machine. Criteria and specifications for designing such programs are known to those of ordinary skill in the art.

Contrary to the prior art, the grinding allowance, corresponding to the accuracy of the measuring system, is known with the inventive method. The grinding program with, in each case, the optimum delivery program is determined with that according to the methods customary in grinding technique. This means that the grinding program is adapted accurately in each case, the fastest possible delivery rate is determined, at which there still is no overheating of the workpiece, and the finished contour is attained accurately. For determining the delivery programs, at which the advance per revolution of the workpiece is fixed, the energy and power introduced by the grinding process are of considerable importance, so that grinding defects, such as overheating when grinding and soft skin formation can be avoided. Moreover, the permissible advance depends on the material.

Because the thickness of the layer, which is to be ground off, is known precisely, a precise coordination of the rough machining, finishing and fine finishing

process is made possible in the case of the invention. The grinding program, adapted in each case to the grinding allowance that is to be ground off, frequently leads to optimized and shortened grinding times since, for example, the delivery path for the rough machining can be lengthened in comparison to that for the finishing, whereas the air grinding phase is reduced to a minimum or even eliminated.

In a preferred embodiment of the method, a plurality of pre-calculated programs with their respective assignment to a particular contour of the unfinished part is stored in the plant control computer. During the manufacturing process, the program, assigned to the measured contour of the unfinished part, is selected by the plant control computer.

In a different, advantageous further development of the method, it is even possible to calculate the grinding program in line. The energy and/or performance balance can be used here as a criterion for the calculation. The maximum permissible delivery path per revolution of the workpiece forms the basis here as a function of the layer thickness and other conventional parameters and the grinding program with the delivery program, which minimizes the processing time, is determined from this mathematically.

The inventive method can be employed for camshafts with any number of cam lobes as well as for other functional components, which are to be ground. A separate grinding program may be selected for each component. In simpler cases, however, the same grinding program may also be selected for groups of functional components. The data for controlling the grinding machine is transferred either in the block of all grinding programs required for the corresponding parts or piece by piece, as required, immediately after the delivery of the grinding wheel to the corresponding position.

In an advantageous further development of the invention, the components are provided with markings, such as serial numbers, bar codes or the like, which are linked in the plant control computer with the Moss data of the contours of the unfinished part. This data can also be transferred off-line to the control unit of the grinding machine. These codes are led as the shafts are moved into the grinding machine and the associated program is loaded from them. In a further development, the marketing is directly the characterization of the grinding program that is to be used.

The invention is explained in greater detail by means of the examples shown in Figures 1 and 2.

Figure 1 diagrammatically shows the construction of the inventive device for grinding camshafts.

The cam lobe and the position of the contour of the finished part, as well as the lower and upper tolerance limits of the contour of the unfinished part are shown in Figure 2.

Figure 1 diagrammatically shows how the camshaft 1 with the functional component 2, which is to be ground, such as the cam lobe, is located in the measuring station for measuring the contour of the unfinished part at the end of the assembly line (not shown here). The profile data of the cam lobe 2 are determined with sensor technology 13 used for measuring, in the present example a measuring stylus or a laser triangulation device. The values measured are provided over the signal lead 9 to a plant control computer 5. The plant computer 5 has a data memory 7 for storing several grinding programs, which contain, input programs, particularly delivery programs. Moreover, the plant control computer 5 has an arithmetic unit 6, a second data memory 8 and appropriate internal data leads 10, which are realized usually by a data bus. In the arithmetic unit 6 of the plant control computer 5, an appropriate grinding program is

selected from the data memory 7 and filed in the data memory 8 on the basis of the input of the value measured at the signal lead 9. The appropriate grinding program, which contains, in particular, the corresponding delivery program, is transferred to the control unit 4 of the grinding machine 3 over the data lead 11.

Parallel to this, the camshaft 1 is brought into the grinding machine 3 for processing by means of an appropriate transfer manipulation 14, such as a robot. The data, required for controlling the grinding machine, I transferred over control signal leads 12a and 12b and the camshaft 1 is ground in accordance with the control program selected.

In a modification of the method described above, the camshaft, after the contour of the unfinished part is measured, is marked clearly (for example, with a bar code) and an identification signal for identifying the camshaft in the grinding machine is also transferred over the control lead 12a to the control unit 4. The marking contains information about the contour of the unfinished part measured or the grinding program that is to be selected. Subsequently, the control unit 4 selects the appropriate grinding program from an allocation of identification signals to the grinding programs.

In an alternative embodiment, the control unit 4, starting out from the identification signal, requests the grinding program from the plant control computer 5.

Pursuant to the invention, the plant control computer 5 and the control unit 4 may be integrated in one computer unit 15. The precise configuration of the computer unit may, however, be very different. The data leads 9, 10, 11, 12a, 12b may also be integrated in a bus system, as is customary in mechanical engineering.

The prior art and the inventive method are compared by means of Table 1 and Figure 2. A camshaft 1 with cam lobes 2, the oversize of the unfinished parts of

which lies within the enveloping curves 17 to 18, has been selected as an example. After the installation, this oversize of the unfinished parts relative to the contour 16 of the finished part, which is also referred to as allowance, fluctuates in the example from the contour of the finished part plus 0.1 mm (enveloping curve 17) to a finished dimension plus 0.5 mm (enveloping curve 18). Moreover, the oversizes at all points of the outer peripheral contour of the cam lobe must lie between the enveloping curve 17 and the enveloping curve 18. In the example selected, the actual oversize at any point of the contour is 0.35 mm.

The grinding wheel must be delivered at such a rate, that it does not dip into the surface of the workpiece at the highest speed used for moving the wheel up to the workpiece.

In accordance with the state of the art, as shown in the left half of Table 1, the grinding wheel is therefore moved up to the enveloping curve 18 for the largest possible oversize. Subsequently, a certain delivery path is covered for each revolution of the workpiece until, in the last step, which is the seventh revolution here, there is "free sparking" with a delivery of 0 mm and the workpiece has been ground to the finished contour 16. According to the prior art, this means 7 deliveries with a total delivery path of 0.5 mm. The whole process time then is approximately 7 seconds, for example.

As can be seen from the Table, the delivery, however, was carried out for a distance of 0.15 mm with a speed, adapted for the grinding, although no material was ground off. This process is also referred to as air grinding in the industry.

This air grinding is eliminated completely with the inventive method, as shown in the right half of Table 1. Delivery takes place directly to the enveloping curve of the measured oversize, which is + 0.35 mm here. The grinding operation is completed

in 5 further revolutions of the workpiece. In the example given, the process time saved is about 2 seconds per cam lobe.

As furthermore shown in Table 1, the deliveries for the first two revolutions are greater in the case of the inventive method than in the case of the prior art. An advantageous further development of the method is shown here, for which the delivery rate is adapted to the thickness of the oversize. For relatively large oversizes, grinding is usually carried out at a high delivery rate (rough machining). Only when the oversize is small is the delivery rate lowered (finishing, fine finishing or spark machining). The high delivery rate during the rough machining must be such that excessive power is not introduced into the workspace and that, correspondingly, there is no overheating of the workpiece. For example, for an oversize of 0.500 mm, a delivery of 0.400 mm per 4 revolutions up to an allowance of 0.100 mm and a corresponding introduction of power may be provided. However, if the oversize is only 0.350 mm, this delivery can even be increased up to and allowance of 0.100 mm. However, the total delivery must not exceed the value of the original power introduction. The time-shaving volume may be used as a measure of this.

Table 1

	Delivery according to prior art				Delivery according to inventive method			
	Allowance in mm	Workpiece revolution	Delivery in mm	Air grinding in mm	Allowance in mm	Workpiece revolution	Delivery in mm	Air grinding in mm
	0.350	1	0.100	0.100				0.000
	0.350	2	0.100	0.050				0.000
	0.300	3	0.100	0.000	0.350	1	0.130	0.000
	0.200	4	0.100	0.000	0.220	2	0.120	0.000
	0.100	5	0.070	0.000	0.100	3	0.070	0.000
	0.030	6	0.030	0.000	0.030	4	0.030	0.000
	0.000	7	0.000	0.000	0.000	5	0.000	0.000
Total	0.350	7	0.500	0.150	0.350	5	0.350	0.000

Over and above the advantages described, the inventive method offers further important advantages. For example, the measurement enables the shafts, for which the contour of the unfinished part of the functional components is already too small, that is, no longer lies within the tolerance range, to be sorted out before the grinding. In this case, the shaft can no longer meet specifications, so that grinding no longer is necessary. As a result, rejects are not processed further and the processing times and costs, required for this, are saved.

An even larger advantage can be seen therein that workpieces having an oversize, which goes beyond the maximum permissible enveloping curve 18, can be processed without sequential damage, so that it becomes possible to lower the tolerance requirements partly or for the time of particular production problems.

Furthermore, the quality of unfinished parts can be specified with a statistical range, so that early recognition of problems in the offing in the case of future manufacturing processes becomes possible.

It is obvious that the method and device described here can also be used for components other than constructed camshafts. For example they may also be used for cast and forged camshafts, crankshafts, control shafts and for the grinding of points of support for transmission shafts.

List of Reference Symbols

1	camshaft
2	functional component, cam lobe
3	grinding machine
4	control unit
5	plant control computer
6	arithmetic unit
7	data memory
8	data memory
9	signal lead
10	internal data lead
11	data lead
12a	control signal lead
12b	control signal lead
13	sensor technology, measuring stylus
14	supplying camshaft to grinding machine, transfer treatment
15	arithmetic unit
16	contour of finished part
17	enveloping curve, lower tolerance limit of the contour of the unfinished part
18	enveloping curve, upper tolerance limit of the contour of the unfinished part